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Effect of hot air temperature on drying kinetics of palmyra (*Borassus aethiopum* Mart.) seed-sprout fleshy scale slices and quality attributes of its flour

Joseph Kudadam Korese [a,*], Matthew Atongbiik Achaglinkame [a], Solomon Kofi Chikpah [b]

[a] Faculty of Agriculture, Food and Consumer Sciences, Department of Agricultural Mechanisation and Irrigation Technology, University for Development Studies, Post Office Box TL 1882, Nyankpala Campus, Ghana
[b] Faculty of Agriculture, Food and Consumer Sciences, Department of Food Science and Technology, University for Development Studies, Post Office Box TL 1882, Nyankpala Campus, Ghana

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ABSTRACT

This study investigated the influence of different drying air temperatures (40, 50, 60 and 70 °C) on moisture removal ratio and drying rate of pre-cooked and uncooked palmyra (*Borassus aethiopum*) seed-sprout fleshy scale (SFS) slices and quality of the resultant flours. Through drying kinetic analysis, it was found that the drying process of pre-cooked and uncooked palmyra SFS slices took place in the falling rate period and the drying time decreased with increasing air temperature in all samples. The colour parameters (L*, a* and b*) were affected by the drying air temperature and treatment type (pre-cooked and uncooked), with significantly higher ΔE values in uncooked samples compared to the pre-cooked samples. Drying of uncooked SFS slices maintains relatively high total antioxidant activity and low content of vitamin C compared to the pre-cooked samples. Beta-carotene, total phenol and total flavonoid contents however showed no specific trend in pre-cooked and uncooked SFS samples. Generally, pre-cooking palmyra SFS before drying significantly ($P < 0.05$) improved their water absorption capacity, swelling index and swelling capacity while decreasing bulk density. However, treatment type and drying air temperature was observed to greatly ($P < 0.05$) influenced all pasting properties without any observable trend. Based on the results, the quality of palmyra SFS flour showed opposite behaviours, thus indicating a compromise decision on processing conditions involved to meet the quality properties of interest.

1. Introduction

Palmyra (*Borassus aethiopum* Mart.) (Fig. 1) is an underutilized dioecious plant which belongs to the family Arecaceae [1]. The tree is native to tropical Africa and is well known for its high economic, cultural, medicinal and nutritional importance [2–5]. Palmyra provides a wide range of edible and non-edible products which are used for various purposes [6]. One of such edible parts is the seed-sprouts which are regarded as common foodstuffs for many populations where the plant grows [7]. The seed-sprouts serves as a cheap source of starch, carbohydrates, fats, some minerals and some health promoting bioactive compounds [2,8,9]. Other studies have revealed that the seed-sprouts serves as major constituents of most traditional medicine, used for the treatment of malaria, infections/infestations and respiratory system disorders, nervous system disorders as well as impotence and sexual weakness in men [5].

Despite the numerous benefits, fresh palmyra seed-sprouts are susceptible to deterioration at harvest and during storage due to its high moisture content (~75% wet basis) [10]. This gives rise to the need for preservation of harvested seed-sprouts. Drying is one of the most common methods used to extend the shelf-life of food and agricultural products through the reduction of the moisture content to a lower water activity level that inhibits microbial, enzymatic and quality decay [11]. Drying also reduces the storage as well as transportation cost and explores the way for utilization of such in different products without any seasonal limitations [12]. The advantages and applicability of traditional and hybrid drying techniques has been reported in the literature for different vegetables, fruits, and aquatic products [13,14]. Nevertheless, food and pharmaceutical industries still prefer hot air drying due to its low cost and wide applicability [15]. Previous studies have shown

* Corresponding author.
E-mail address: jkorese@uds.edu.gh (J.K. Korese).

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Fig. 1. Palmyra tree.

that drying conditions during hot air drying could affect dried products qualities associated with colour and bioactive compounds degradations as well as functional and pasting properties of the final product [16,17]. The quality of the product obtained after the drying process is important because minimal damage to bioactive compounds such as ß-carotene, vitamin C, phenols, flavonoids, anti-oxidative potential as well as functional and pasting properties could govern their usage in value-added foods and various food products where thickening potential of derived flours are desirable.

Different studies have been conducted on processing of palmyra fruits, nuts and seed-sprouts/shoots including development of novel food products and determination of qualitative parameters [18–21]. Abe-Inge et al. [22] developed flour from African palmyra fruit and also evaluated the effect of different drying methods on the quality characteristics of the flour. Ramachandran and Rajendran [10] evaluated the effect of different drying methods on the drying kinetics of palmyra (*Borassus flabellifer)* sprouts. However, the study did not evaluate the effect of any treatment such as drying time or temperature on the quality of the resultant flours. Moreover, in these studies limited information is reported on hot air drying and the effects of treatment such as pre-cooking and air temperature on drying kinetics and quality of palmyra *(Borassus aethiopum)* seed-sprout flours. Considering these gaps, the present study was planned to investigate the effect of pre-treating palmyra seed-sprouts and different drying air temperatures on the drying behavior and phytochemical and physico-functional properties of the resultant flour for efficient utilization as food ingredient in processed products.

2. Materials and methods

2.1. Raw material and sample preparation

Freshly harvested palmyra (*Borassus aethiopum*) seed-sprouts

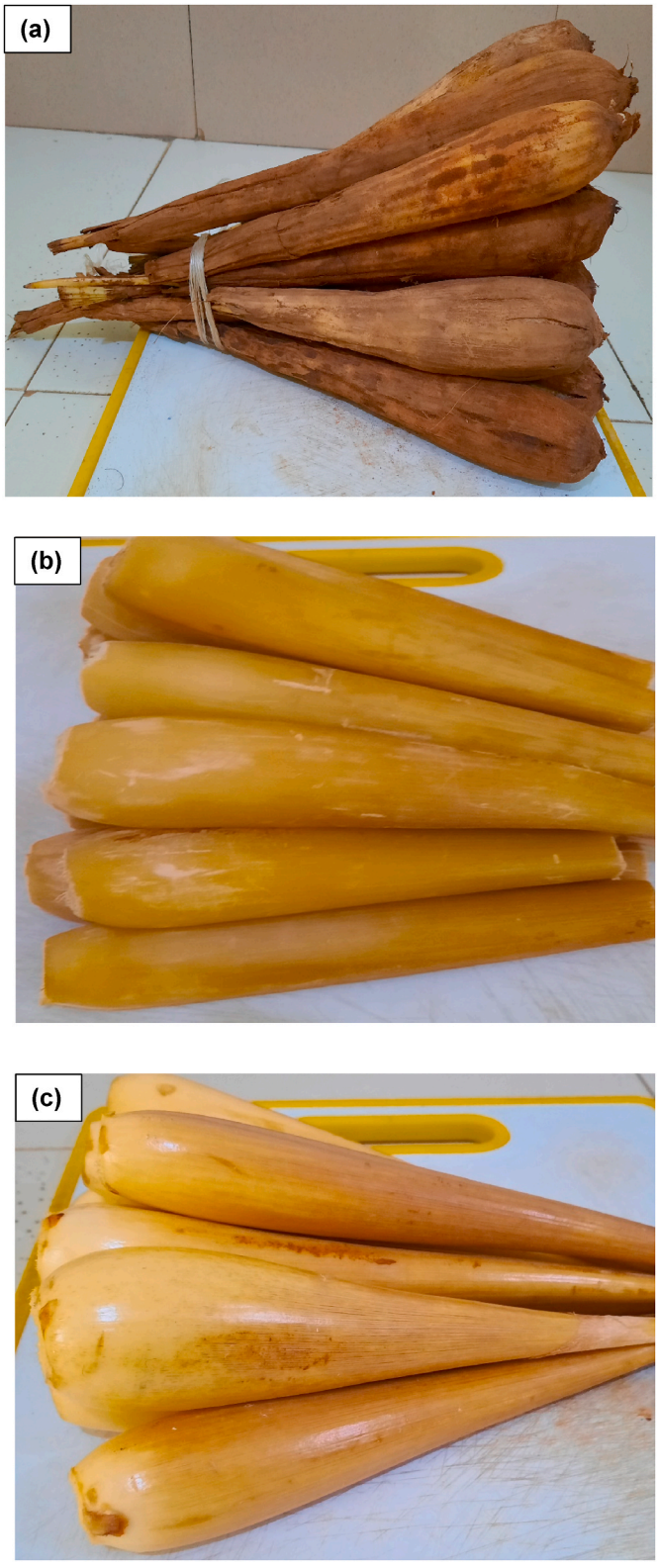

Fig. 2. (a) Freshly harvested palmyra seed-sprouts, (b) pre-cooked palmyra seed-sprout fleshy scales, (c) uncooked palmyra seed-sprout fleshy scales.

(Fig. 2a) were collected from a grower in Langbensi, East Mamprusi District of the North East Region of Ghana. The average weight, length and diameter of whole seed-sprouts were 100.28 ± 18.44 g, 23.8 ± 1.79 cm and 7.59 ± 0.26 cm, respectively. The fresh palmyra seed-sprouts were thoroughly washed with tap water to remove soil and sand, peeled and the shoots removed. The seed-sprout fleshy scales (SFS) were then prepared for the study. Two kinds of samples were compared in this study: pre-cooking of palmyra SFS in distilled water for 15 min [23] and uncooked SFS samples. The pre-cooked and uncooked SFS samples (Fig. 2b and c) were then uniformly sliced into 3 mm thickness using an electrical slicing machine (Ritter E16, Ritter GmbH, Germany).

2.2. Drying process of palmyra seed-sprout and flour preparation

Palmyra SFS slices were dried at different air temperatures (40, 50, 60 and 70 °C) using a bench top "Hohenheim HT mini" cabinet dryer (Innotech-Ingenieursgesellschaft mbH, Altdorf Germany), which allowed for control of air temperature (±2 °C) with a constant air speed [24]. The drying system is shown in Fig. 3. The temperature and relative humidity of the surroundings in the laboratory room were at the range of 31.6 °C to 32.5 °C and from 38.5% to 40.0%, respectively. Before the start of the experiments, the drying system was run for about 30 min to obtain steady-state conditions. For each drying trial, about 300 g of the sample was spread in a single layer on a perforated tray with dimensions 433 x 385 × 22 mm (L x W x H). The samples were then inserted into the drying chamber and exposed to the drying air. Weight loss during drying was monitored every 30 min interval [25–27] with the aid of a weighing scale (PCB 10000-1, KERN & SOHN GmbH, Ziegelei 1, Balingen – Germany) until a constant weight was obtained. Removing, weighing, colour measurement and returning of the SFS sample during off-line measurements took approximately 25 s [28,29], and did not significantly alter the drying air conditions. Drying experiments were replicated three times and average values were reported. After drying, the samples were allowed to cool under room temperature (25 ± 1 °C), milled into flour and sieved with a 250 μm aperture mesh (Setaccio Di Prova, Laboratory test sieve, Milano, Italy). The flours were packed into high-density polyethylene (HDPE) bags and stored under refrigeration (4 ± 1 °C) for further analyses. Fig. 4 shows a flow chart for processing palmyra seed-sprout fleshy scales flours.

2.3. Drying kinetics of palmyra seed-sprout slices

The drying data of the palmyra SFS obtained were transformed into dimensionless moisture ratio (MR). The MR and the drying rate of the slices during drying was calculated using Eq. (1) and Eq. (2), respectively [30].

Fig. 3. Picture of the experimental bench top cabinet dryer.

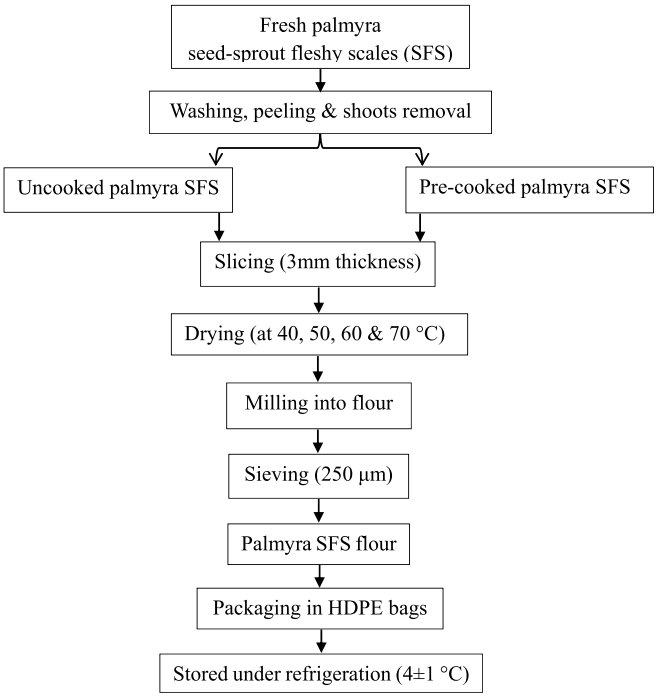

Fig. 4. Flow chart for processing palmyra seed-sprout fleshy scales flours.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

$$Drying\ rate = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

Where, M_t and M_{t+dt} is moisture content at time t and t + dt (g water/g dry matter) respectively, M_0 is initial moisture content, M_e is equilibrium moisture content (g water/g dry matter) and dt is infinitely small change in time.

Modelling of the drying kinetics was performed using Solver function in Microsoft Excel version 2016, which enabled fitting of basic drying models to experimental points. Preliminary tests conducted in this study showed that the best fitting was obtained for the Page model (Eq. (3)); consequently only this model was used in this study. The Page model has been successfully used to describe the drying curves of various agricultural products [15,30,31]. The goodness of fit of the model was evaluated with the coefficient of determination (R^2) and root mean square error (RMSE). The model fit better if the value of R^2 is higher and RMSE value is closer to 0.

$$MR = exp[-kt^n] \quad (3)$$

Where k, n are model constants and t is time.

2.4. Water activity measurement

Water activity was determined by placing approximately 4.50 g of suitably crushed samples of dried SFS in a sample holder of a water activity meter (Labswift-aw, Novasina AG, Switzerland) at room temperature (25 ± 1 °C). All measurements were conducted in triplicates.

2.5. Colour determination

Colour parameters (L*, a* and b*) of fresh and dried palmyra SFS slices were measured using a handheld chroma meter (CR-400, Konica Minolta Inc., Japan). Prior to the experiments, the instrument was

calibrated with a standard white plate at D65 illumination (Y = 80.1, x = 0.3219, y = 0.3394). After every 30 min interval during the drying process, SFS samples were taken out of the drying chamber and L*, a* and b* were measured [32]. Colour measurements were taken in sextuplicate and averaged. The colour degradation of palmyra SFS slices was expressed as a single numerical value ΔE which was calculated using Eq. (4). The ΔE defines the magnitude of the total colour difference in the fresh palmyra SFS slices during drying.

$$\Delta E = \sqrt{\left(L_o^* - L^*\right)^2 + \left(a_o^* - a^*\right)^2 + \left(b_o^* - b^*\right)^2} \quad (4)$$

Where ΔE is total colour change, L_o^*, a_o^*, b_o^* are lightness, redness/greenness, yellowness/blueness respectively of SFS sample before drying and L^*, a^*, b^* are lightness, redness/greenness, yellowness/blueness respectively of dried SFS sample.

2.6. Beta-carotene content determination

The beta-carotene content in the palmyra samples was determined in accordance with the methods of AOAC [33] using a spectrophotometer (UV/VIS Excellence UV5, Mettler Toledo, Switzerland) at 450 nm. Vitamin A as ß-carotene in the flours was calculated by the conversion ratio of 13 μg ß-carotene:1 μg retinol activity equivalent for vitamin A [34].

2.7. Vitamin C content determination

The vitamin C content of the samples was determined using the titration method [33]. About 5 g of each sample was weighed into a 250 mL conical flask and 50 ml of distilled water and 1 mL of starch indicator solution were then added. The sample was then titrated with 0.005 mol iodine solution. The endpoint of the titration was identified as the first permanent trace of a dark blue-black colour due to the starch-iodine complex. The titration was repeated with further aliquots of sample solution until concordant results were obtained.

2.8. Extract preparation and determination of antioxidant properties

Palmyra SFS flour samples were extracted using the procedure described by Izli et al. [35] with little modification. About 2 g of the flour sample was mixed with 16 mL of 80/20 v/v of methanol/water and centrifuged at 3000 rpm for 15 min using a Rotofix 32 A centrifuge (Andreas Hettich GmbH and Co. KG, Tuttlingen, Germany). The supernatant was collected and the residue was further subjected to the same extraction procedure two more times. The supernatants were then combined and filtered with a membrane filter. Total phenol content of the samples was determined as described by Singleton et al. [36] with a spectrophotometer (UV/VIS Excellence UV5, Mettler Toledo, Switzerland) at 745 nm. Phenol content was read as gallic acid equivalence (GAE). This procedure was replicated thrice for each sample. Total flavonoid content of the palmyra SFS flour samples was measured using procedures outlined by Meda et al. [37] at 415 nm with a spectrophotometer (UV/VIS Excellence UV5, Mettler Toledo, Switzerland). The total flavonoid values were expressed as quercetin equivalence (QE). Total antioxidant activity of the samples was determined by the phosphomolybdenum complex method described by Prieto et al. [38] and the values were expressed as ascorbic acid equivalence (AAE). The measurement was repeated thrice and the average values were then reported.

2.9. Functional properties

Water absorption capacity (WAC) was determined following the method described by Lawal [39] with little modifications. Approximately, 1 g of flour of each sample was weighed into a 15 mL Falcon test tube and 10 mL of distilled water added and thoroughly mixed for 30 s. The mixture was allowed to rest for 30 min at room temperature (25 ± 1 °C) and centrifuged at 3000×*g* for 30 min (HITACHI SCR20BC, Tokyo, Japan). After the centrifugation, the remaining water was gently transferred to a 15 mL Falcon test tube and the volume noted and subtracted from the 10 mL to compute the water absorption capacity using Eq. (5).

$$\text{Water absorption capacity (mL/g)} = \frac{\text{volume of water absorbed}}{\text{Weight (g) of flour}} \quad (5)$$

Swelling index (SI) and swelling capacity (SC) were determined following the methods described by Abbey and Ibeh [40] with modifications. About 1 g of the sample was weighed into a clean dry measuring cylinder and the volume occupied by the sample was recorded. About 10 mL of distilled water was then added to the sample and allowed to stand undisturbed for an hour, after which the volume was observed and recorded again. The swelling index of the sample was calculated as the ratio of the volume after swelling to the ordinary volume of a unit weight of the flour before swelling. The swelling capacity was calculated as the ratio of the weight of wet gel obtained to the weight of sample used expressed as a percentage.

The method described by Que et al. [41] with slight changes was employed for the determination of bulk density of the palmyra SFS flour. About 100 g of the flour was measured using a precision balance (model: PBJ 620-3 M, KERN & SOHN GmbH, Germany) and transferred into a 250 mL measuring cylinder and the volume of flour was recorded after gentle tapping on the bench surface severally till there was no observable change in volume. The bulk density was expressed as the weight of flour per volume of the same flour (g/mL).

2.10. Pasting properties

Pasting properties of the palmyra SFS flours were determined in duplicates in accordance with Eriksson [42] using a Rapid Visco Analyzer (RVA Model 4500, Perten Instrument, Australia). The RVA was connected to a personal computer equipped with the manufacturer's Thermocline for Windows (TCW) software for operations and data handling. Viscosity profiles of the flours were recorded using 3 g of flour in 25 ml of water at 14% moisture content in a canister. Temperature-time conditions included heating the slurry at 50 °C for 1 min and then heating to 95 °C and held at this temperature for 10 min followed by cooling to 50 °C and holding for 2 min at the same temperature. A rotation speed of 960 rpm was set for the first 10 s and of 160 rpm until the end of the mixing. Pasting properties such as peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time, and pasting temperature were the parameters recorded.

2.11. Statistical analysis

The data obtained were analyzed by analysis of variance (ANOVA) using GenStat statistical package (12th edition) to study the effects of operating variables on the quality attributes of dried palmyra SFS products. Means were compared at a confidence level of 95% (p = 0.05) by Tukey's comparison test.

3. Results and discussion

3.1. Drying kinetics

The drying behaviour of pre-cooked and uncooked palmyra SFS slices dried at 40, 50, 60 and 70 °C are shown in Fig. 5. Table 1 shows constants of the Page model and the comparison criteria used to assess the fit quality. Solid lines in Fig. 5a and c represent predicted values of MR for each sample. These values indicate that there was a good agreement between the experimental data and the thin-layer model.

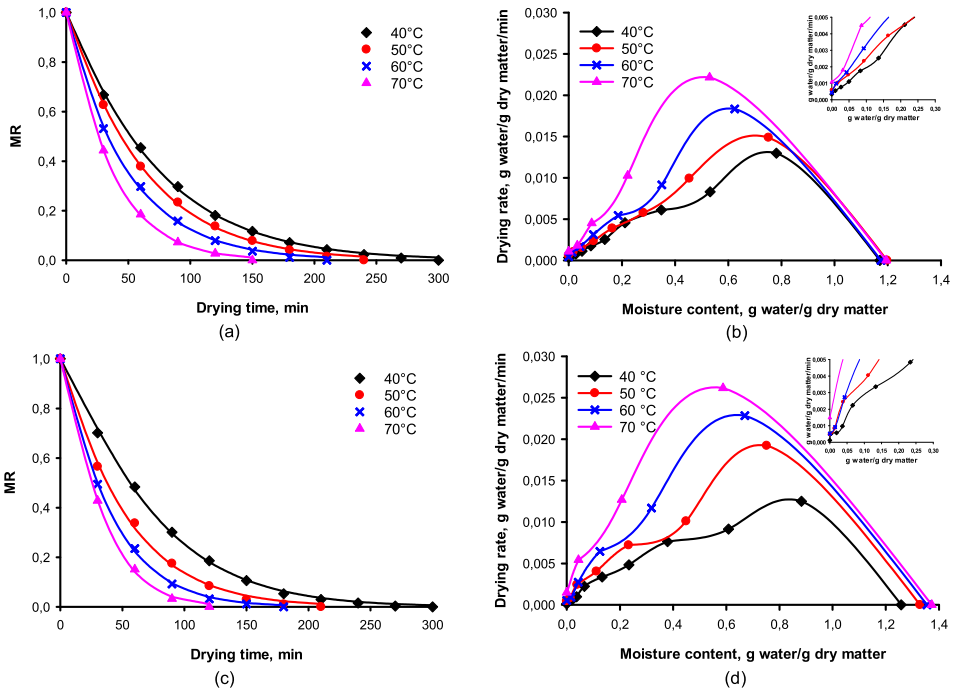

Fig. 5. Effect of drying air temperature on moisture ratio and drying rate of pre-cooked and uncooked palmyra SFS slices. (a) MR of pre-cooked palmyra SFS, (b) drying rate of pre-cooked palmyra SFS, (c) MR of uncooked palmyra SFS, (d) drying rate of uncooked palmyra SFS. Solid lines in Fig. 5(a) and (c) correspond to Page model.

Table 1
Page model constants and coefficients of pre-cooked and uncooked palmyra SFS samples dried at different drying air temperatures.

Treatment type	Temperature (°C)	Constants		Statistics	
		k	n	RMSE	R^2
Pre-cooked	40	0.0100	1.0710	0.0074	0.9995
	50	0.0122	1.0683	0.0070	0.9996
	60	0.0194	1.0165	0.0080	0.9995
	70	0.0209	1.0752	0.0046	0.9999
Uncooked	40	0.0058	1.1867	0.0084	0.9994
	50	0.0135	1.0856	0.0126	0.9987
	60	0.0158	1.1124	0.0064	0.9997
	70	0.0133	1.2189	0.0075	0.9997

Generally, drying air temperature significantly ($p<0.05$) influence the drying time for both pre-cooked and uncooked palmyra SFS slices (Fig. 5a and c). The increase in drying air temperature led to shorter drying duration which is in agreement with most roots, tubers and vegetables [31,32,43]. Dried palmyra SFS slices that were uncooked took 285, 210, 180 and 120 min to reach final moisture content at 40, 50, 60 and 70 °C, respectively which represent a reduction of 5%, 14%, 17% and 25% when compared with the drying times required for pre-cooked palmyra SFS slices of the same drying air temperature. Differences in the drying curves and time of pre-cooked and uncooked palmyra SFS slices could be attributed to changes in the nature of the starches as a result of heating. Pre-cooking may have caused gelatinization of palmyra SFS slice starches resulting in the formation of a resistance film layer on the surface of the samples and hence decreasing the rate of moisture movement during drying [27]. Similar findings have been reported in the literature [44-46]. Variations were observed in the drying rates of the palmyra slices for the different treatment and drying air temperature (Fig. 5b and d). The drying rate at the beginning of the process was low at 40 °C for both samples with a marked difference between this temperature and the other drying air temperatures. This is because, at low drying air temperature, the rate of heat transfer is slower compared with higher drying air temperatures, hence the wide gap in the curves with 40 °C was observed than 50, 60 and 70 °C (Fig. 5a and c). Drying of palmyra SFS slices occurred in falling rate and no constant rate period was observed in any of the experimental treatments and runs for the entire duration. Drying in falling rate period generally suggest that, internal mass transfer has occurred by diffusion control process and may be represented by Fick's second law of diffusion [30,31]. With regards to the final moisture content, the dried samples showed a moisture content in the ranges of 7.5 to 10.0% wet basis (w.b) and 5.1 to 8.7% w.b, respectively, for pre-cooked and uncooked palmyra SFS slices. Water activity values obtained for pre-cooked and uncooked dried samples were respectively within the range of 0.348 to 0.448 and 0.132 to 0.334 which are considered positive for dried products stability due to the low presence of free water available for microorganism development and biochemical reactions during storage [47].

3.2. Colour changes during drying process

Figs. 6 and 7 show the evolution of colour parameters, L*, a*, b* and ΔE of pre-cooked and uncooked palmyra SFS slices during convective air drying at different drying air temperatures. The colour parameters L*, a* and b* of fresh palmyra SFS slices were 55.04 ± 1.37, -2.94 ± 0.32 and 25.16 ± 1.91, respectively. Generally, changes in L*, a* and b* during drying of pre-cooked and uncooked palmyra SFS slices were affected by the drying air temperature but without any observable trend (Figs. 6 and 7). Similar observations about changes in L*, a* and b* values were reported by Ramallo and Mascheroni [48] during pineapple fruit drying. As drying progressed in each drying air temperature, an initial increase and then decrease trend in L* was observed in the pre-cooked and uncooked palmyra SFS slices (Figs. 6a and 7a). Lightness was generally higher in uncooked samples than the pre-cooked samples, suggesting that the latter causes browning of the sample. Regarding redness as shown in Figs. 6b and 7b, a* values decreased at the initial stage of the drying process and then increased during drying at 40, 50, 50 and 70 °C for pre-cooked palmyra SFS slices and 40 and 60 °C for uncooked palmyra SFS samples. The redness values of uncooked palmyra SFS slices at 50 °C however increased slightly as drying progressed but practically

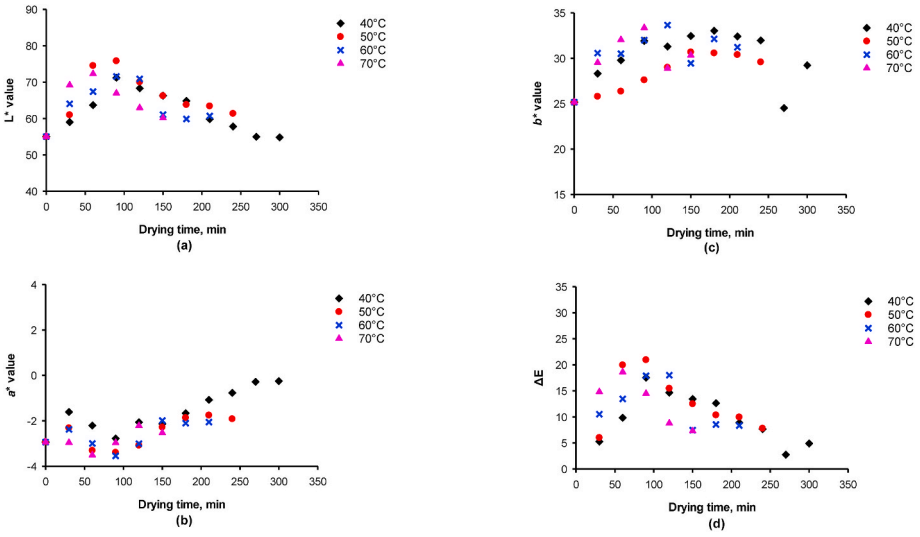

Fig. 6. Evolution kinetics of L*, a*, b* and ΔE of pre-cooked palmyra SFS slices at different drying air temperatures.

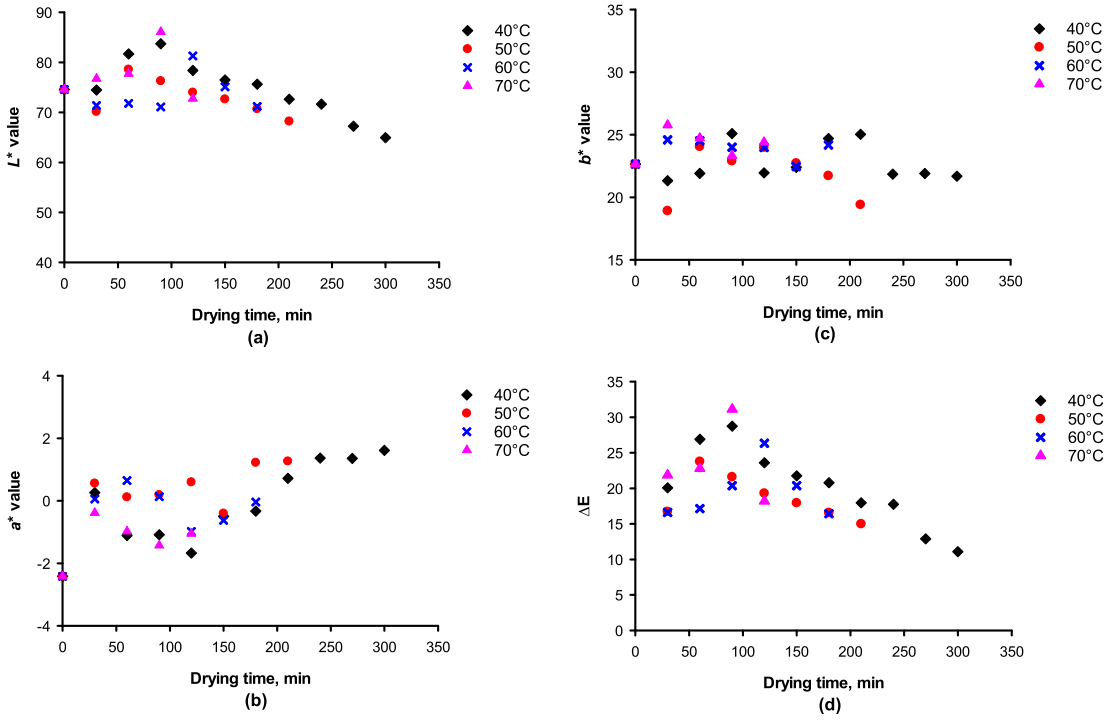

Fig. 7. Evolution kinetics of L*, a*, b* and ΔE of uncooked palmyra SFS slices at different drying air temperatures.

remained without changes during drying at 70 °C. Furthermore, a* values obtained at the end of drying were generally lower in pre-cooked palmyra samples as compared to the uncooked palmyra SFS samples. This may be due to the formation of more degradable sugar during pre-cooking treatment, which led to a browning reaction [46]. As shown in Figs. 6c and 7c, it can be observed that b* values generally increased at 50 °C at the beginning of the drying process and later decreased as drying progressed. There was however no observable trend at 40, 60 and 70 °C for both pre-cooked and uncooked palmyra slices. The relative yellow colour (b* value) in the pre-cooked samples was however significantly ($p<0.05$) higher than in the uncooked samples. Overall, ΔE was significantly higher (11.09–31.12) in the uncooked samples compared to the pre-cooked samples (2.73–20.95) with ΔE increasing rapidly during the first hours of drying before decreasing (Figs. 6d and 7d). Consumers prefer visible colour of food products, therefore, ΔE values can be important for dried palmyra SFS flours, which expresses the human eye's ability to differentiate between colors of food sample [49]. According to Bodart et al. [50], when ΔE is higher than 1–3, the colour changes can be detected by the human eye. Therefore, the variation in the colour attributes in both pre-cooked and uncooked palmyra SFS slices can be perceived during the entire drying process.

3.3. Nutritional properties

Fig. 8 depicts ß-carotene, vitamin C, total phenol and total flavonoid contents of pre-cooked and uncooked palmyra SFS slices at different drying air temperatures. Higher ß-carotene (1.175 mg/100 g) retention was observed at 60 °C for the pre-cooked samples than at other drying

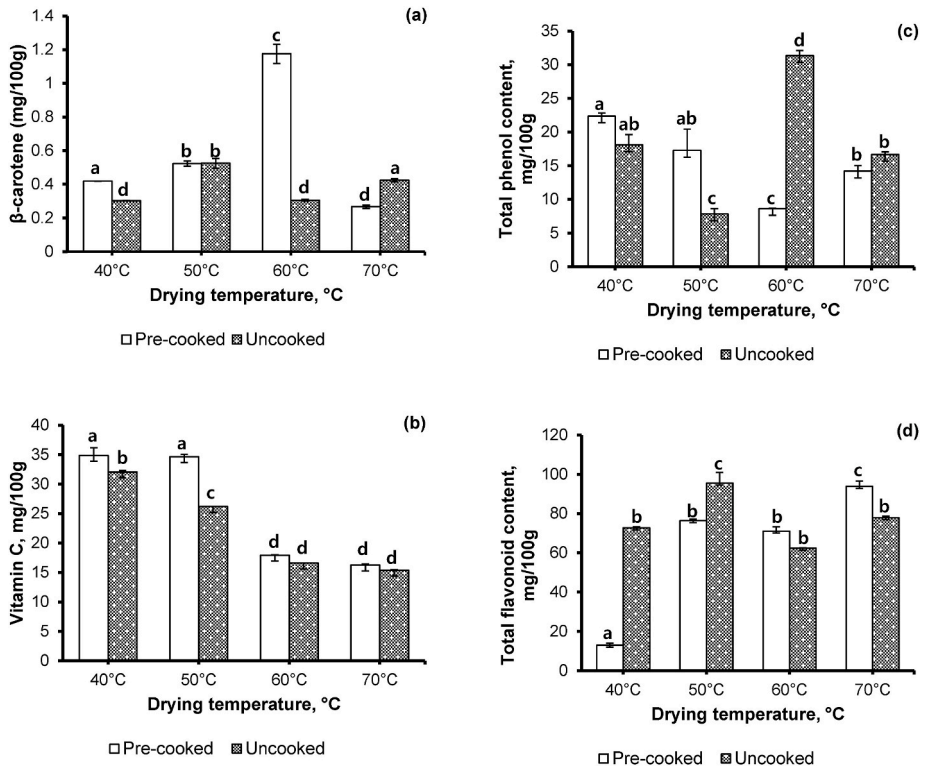

Fig. 8. Effect of different drying air temperatures (40, 50, 60 and 70 °C) on ß-carotene, vitamin C, total phenol and total flavonoid contents of pre-cooked and uncooked palmyra SFS slices. Different letters over the bars imply that values are significantly different ($p<0.05$).

air temperatures (Fig. 8a). This might be due to prolongation in the drying time in the case of 40 °C and elevated drying air temperature in the case of 70 °C, which resulted in more losses of ß-carotene. Cui et al. [51] reported ß-carotene retention of about 85.5% during hot air drying of blanched carrots at 60 to 65 °C. Koca et al. [52] and Nascimento et al. [53] reported that blanching enhances the stability of carotenoids in carrot and sweet potato, which can be ascribed to the inactivation of peroxidase and lipoxidase activity [54].

High vitamin C content (16.25–34.88 mg/100 g) was observed in the pre-cooked samples in comparison to uncooked samples (15.38–32.06 mg/100 g) as shown in Fig. 8b. From these results, it seems heat induced inactivation of ascorbic acid oxidase during pre-cooking slowed down degradation rate of vitamin C [55]. The results are in accordance with the literature where it has been reported that blanching retained higher vitamin C when compared to unblanching in various fruits and vegetables [56]. An increase in the drying air temperature generally resulted in a decrease in vitamin C in both pre-cooked and uncooked samples. However, the decrease in vitamin C was not significant ($p>0.05$) between 60 and 70 °C. According to Vega-Gálvez et al. [57], the reduction in vitamin C with an increase in temperature may be due to irreversible oxidative processes that occur during drying and the fact that vitamin C is a heat-sensitive nutrient.

There was a variation of 8.63–22.36 mg/100 g for the pre-cooked samples and 7.82–31.33 mg/100 g for the uncooked in terms of total phenol content (Fig. 8c). Both treatment type and drying air temperature had a great influence ($p<0.05$) on the total phenol content of the samples without a specific trend. Total flavonoid ranges were 12.94–93.83 mg/100 g and 62.36–95.43 mg/100 g for the pre-cooked and uncooked samples, respectively. Treatment type had a significant effect ($p<0.05$) on the flavonoid content, with the uncooked samples registering higher values than the pre-cooked. Likewise, temperature also influenced flavonoid content markedly without a specific trend.

Antioxidant activity which denotes the ability of antioxidants to inhibit oxidative reactions was greatly influenced by treatment type and temperature. The total antioxidant activity (Fig. 9) of the pre-cooked samples was relatively lower (44.57–53.58%) than that of the uncooked (63.45–84.94%). Findings of this study showed that the uncooked samples averagely had higher values of the bioactive compounds than the pre-cooked. Length of exposure to thermal conditions is reported to have a negative effect on antioxidant activity [58]. It, therefore, suggests pre-cooking may not be ideal as far as the preservation of antioxidant activity is concerned.

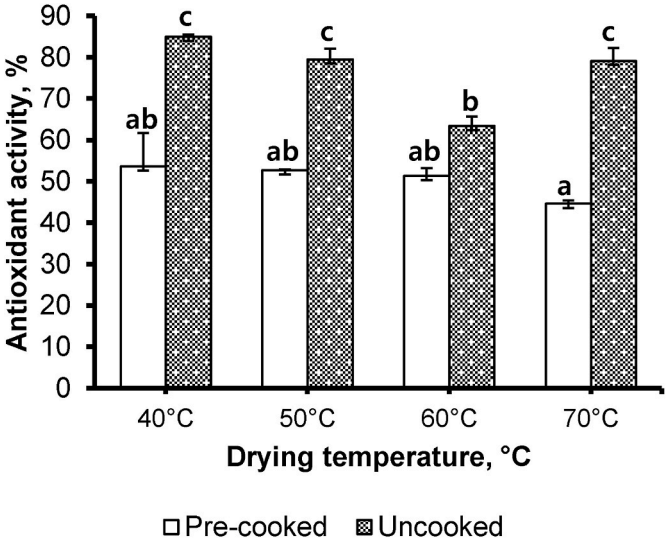

Fig. 9. Effect of different drying air temperatures (40, 50, 60 and 70 °C) on antioxidant activity of pre-cooked and uncooked palmyra SFS slices. Different letters over the bars imply that values are significantly different ($p<0.05$).

3.4. Functional properties

The effect of treatment type and drying air temperature on the functional properties of the palmyra SFS flour are represented in Table 2. Generally, pre-cooking the samples before drying significantly ($p<0.05$) improved the water absorption capacity (WAC), swelling index (SI) and swelling capacity (SC) while decreasing bulk density (BD) of palmyra SFS flour. According to Ikpeme-Emmanuel et al. [59] gelatinization of starch, swelling of crude fibre and denaturation of protein which usually occur during cooking might explain the high WAC values observed in this study. WAC is reported to have a positive link with hydrophilic amino acid and carbohydrate contents of the flour samples [60] and often gives an indication of cohesiveness which is vital for the development of ready-to-eat foods [61]. SI of pre-cooked and uncooked palmyra SFS flour ranged from 4.23 to 4.73 and 1.96–2.49, respectively while SC of same the samples respectively ranged from 11.24 to 11.63 g/g and 8.58–9.09 g/g. Pre-cooked palmyra SFS flours showed high SI and SC values as compared to uncooked palmyra SFS flours. SI and SC are key properties as far as the product's ability to provide satiety is concerned. The high values of SI and SC flour are in no doubt making it an important and economical tool for combating hunger in rural dwellings. It was observed (Table 2) that only BD of both pre-cooked and uncooked palmyra SFS flour samples significantly ($p<0.05$) increased as the temperature of the drying air was increased. Although some statistical differences were found in BD, a relatively narrow range of between 0.82 and 0.88 g/ml and 0.94–0.96 g/ml was detected in pre-cooked and uncooked samples, respectively. High bulk density of flours are generally not suitable in packaging and it may not also result in cost savings as it will require more packaging material [62]. Low bulk density of flour on the other hand will be an advantage in the preparations of weaning food formulations [63].

3.5. Pasting properties

The pasting properties of pre-cooked and uncooked palmyra SFS flour samples dried at different air temperatures are represented in Table 3. It can be observed that treatment type and drying air temperature greatly influenced the pasting properties of the palmyra SFS flours without any observable trend. Peak viscosity (PV) which is a measure of the strength of paste formed as a result of gelatinization during processing [64], is often correlated with product quality. It also indicates the level of granule swelling [65] and the viscous load likely to be encountered during mixing [64]. PV of pre-cooked SFS flours ranged from 2741 ± 26 cP – 3666 ± 23 cP and uncooked SFS flour samples from 2864 ± 13 cP – 3880 ± 17 cP for the drying air temperatures tested. PV values were higher in uncooked palmyra SFS flours as compared to pre-cooked palmyra SFS flours, which might be due to differences in the degree of gelatinization of starch granules [46]. This result is similar to previously reported high PV values for elephant foot yam flours [66].

Trough viscosity (TV), also known as holding viscosity, indicates the minimum viscosity value in the constant temperature phase of the RVA profile and measures the ability of paste to withstand breakdown during cooking. The TV ranged from 2359 ± 12 cP – 2802 ± 26 cP for pre-cooked palmyra SFS flours for the applied hot air temperatures with uncooked palmyra SFS flours having lower values (1237 ± 13 cP – 1651 ± 10 cP), thus signifying low resistance to breakdown. Breakdown viscosity, which is a measure of the degree of disintegration of granules or paste stability during cooking or shear stress [67], varied from 334 ± 47 cP – 865 ± 40 cP and 1507 ± 18 cP – 2229 ± 16 cP for pre-cooked and uncooked palmyra SFS flours, respectively. The lower the breakdown viscosity value, the more stable the starch gel or paste and vice-versa. Mathematically, breakdown viscosity is the difference between peak viscosity and trough viscosity. The low TV values of the uncooked samples therefore account for their high BV values.

Final viscosity (FV) measures the ability of flour to paste after cooking and cooling and the resistance of the paste to shear force during stirring [68]. It can be seen from Table 3 that FV was significantly ($p<0.05$) higher in pre-cooked palmyra SFS flours compared to the uncooked counterparts. This suggests that pre-cooking palmyra SFS before drying makes the resultant flours more viscous and more resistant to shear force. For usage as a complementary food, the uncooked samples may be relatively ideal because of their low final viscosity. Highly viscous foods used for complementary feeding may have to be diluted to reduce the viscosity which may compromise their nutrient concentration. The pre-cooked palmyra SFS flours could be useful as thickening agents because of their high viscosity. Setback viscosity (SV) is an indication of the degree of retrogradation of starch molecules during cooling. SV makes paste firmer, more resistant to enzymic attack, and less digestible [69]. The relatively lower SV values (383 ± 11 cP – 576 ± 56 cP) of the uncooked palmyra SFS samples (Table 3) is an indication of low retrogradation, and high digestibility.

The peak time of pre-cooked and uncooked palmyra SFS flours was comparable for the range temperatures tested, but lower values were obtained in the uncooked samples. Peak time measures the minimum time required for the food sample to reach its highest viscosity during cooking. The result thus suggests that the uncooked samples may need relatively less time to reach their highest viscosity as compared to when pre-cooked. Pasting temperature, a measure of the minimum temperature required for the sample to form a viscous paste during heating, varied from 61.78 ± 0.04 °C–64.43 ± 0.04 °C and 80.60 ± 00 °C–81.60 ± 0.07 °C respectively for pre-cooked and uncooked palmyra SFS flours. The results suggest that pre-cooking the sample prior to drying reduces the temperature required for the flour to form a paste and thus may translate to less energy consumption during cooking. The low pasting temperature observed among the pre-cooked samples may be attributable to the pre-cooking before drying which might have caused pre-gelatinization of starch.

Table 2
Effect of different drying air temperature on functional properties of pre-cooked and uncooked palmyra SFS flour.

Treatment type	Temperature °C	Water absorption capacity (ml/g)	Swelling index	Swelling capacity (g/g)	Bulk density (g/ml)
Pre-cooked	40	3.44 ± 0.08^{a}	4.35 ± 0.16^{a}	11.24 ± 0.05^{a}	0.82 ± 0.00^{a}
	50	3.54 ± 0.07^{a}	4.31 ± 0.11^{a}	11.59 ± 0.19^{a}	0.85 ± 0.00^{b}
	60	3.49 ± 0.14^{a}	4.73 ± 0.38^{a}	11.63 ± 0.23^{a}	0.86 ± 0.00^{c}
	70	3.53 ± 0.07^{a}	4.23 ± 0.12^{a}	11.40 ± 0.03^{a}	0.88 ± 0.00^{d}
Uncooked	40	1.34 ± 0.07^{b}	2.32 ± 0.02^{b}	8.87 ± 0.15^{b}	0.94 ± 0.00^{e}
	50	1.39 ± 0.14^{b}	2.49 ± 0.25^{b}	9.09 ± 0.18^{b}	0.94 ± 0.01^{ef}
	60	1.29 ± 0.00^{b}	1.96 ± 0.05^{b}	8.58 ± 0.07^{b}	0.95 ± 0.01^{f}
	70	1.39 ± 0.14^{b}	1.98 ± 0.27^{b}	8.95 ± 0.15^{b}	0.96 ± 0.00^{g}

Values are presented as mean ± standard deviation. Values with different superscripts are statistically different ($p<0.05$).

4. Conclusions

The effect of drying air temperatures (40–70 °C) on moisture removal ratio, drying rate, phytochemical properties, functional and pasting properties of palmyra SFS slices was investigated. The increase in drying air temperature from 40 to 70 °C reduced the drying time of uncooked palmyra SFS slices by 5%, 14%, 17% and 25%, respectively when compared with the drying times required for pre-cooked palmyra SFS slices. The findings in this study indicate that the three colour parameters (L*, a* and b*) were affected by drying air temperature and

Table 3
Effect of different drying air temperature on pasting properties of pre-cooked and uncooked palmyra flour.

Treatment type	Temperature (°C)	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Peak time (min)	Pasting temperature (°C)
Pre-cooked	40	3125 ± 120^{ac}	2410 ± 3^{a}	715 ± 122^{ab}	3486 ± 112^{a}	1076 ± 115^{a}	5.07 ± 0.19^{a}	61.78 ± 0.04^{a}
	50	2909 ± 194^{ab}	2359 ± 120^{a}	551 ± 74^{bc}	3400 ± 240^{a}	1042 ± 121^{a}	5.33 ± 0.00^{ab}	62.98 ± 0.53^{b}
	60	3666 ± 23^{d}	2802 ± 26^{b}	865 ± 4^{b}	4347 ± 11^{b}	1546 ± 37^{c}	5.10 ± 0.04^{ab}	62.63 ± 0.11^{ab}
	70	2741 ± 26^{b}	2406 ± 21^{a}	334 ± 47^{c}	3698 ± 25^{a}	1292 ± 4^{bc}	5.40 ± 0.10^{b}	64.43 ± 0.04^{c}
Uncooked	40	2864 ± 13^{ab}	1357 ± 5^{ce}	1507 ± 18^{d}	1782 ± 11^{c}	426 ± 16^{d}	4.00 ± 0.00^{c}	81.48 ± 0.11^{d}
	50	3306 ± 79^{ac}	1513 ± 30^{cd}	1794 ± 49^{e}	1991 ± 14^{cd}	479 ± 16^{d}	4.00 ± 0.00^{c}	80.60 ± 0.00^{d}
	60	3880 ± 17^{d}	1651 ± 1^{d}	2229 ± 16^{f}	2227 ± 57^{d}	576 ± 56^{d}	4.00 ± 0.00^{c}	81.15 ± 0.64^{d}
	70	2897 ± 13^{ab}	1237 ± 13^{e}	1660 ± 0^{de}	1620 ± 1^{c}	383 ± 11^{d}	4.00 ± 0.00^{c}	81.60 ± 0.07^{d}

Values are presented as mean ± standard deviation. Values with different superscripts are statistically different ($p<0.05$).

treatment type (pre-cooked and uncooked), showing significantly higher ΔE values in uncooked samples compared to the pre-cooked samples. Drying of uncooked SFS slices maintains relatively high total antioxidant activity and low content of vitamin C compared to the pre-cooked samples. Beta-carotene, total phenol and total flavonoid contents however showed no specific trend in pre-cooked and uncooked SFS samples. On the other hand, pre-cooking of palmyra SFS before drying significantly ($P < 0.05$) improved their water absorption capacity, swelling index and swelling capacity while decreasing bulk density. The treatment type and drying air temperature also greatly ($P < 0.05$) influenced peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time, and pasting temperature but without any observable trend. Based on the results, the quality of palmyra SFS flour showed opposite behaviours, thus indicating a compromise decision on processing conditions involved to meet the quality properties of interest.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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